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Abstract

In order to provide a safe, repeatable, precise, high-gain flying qualities task a ground deployed system was developed and tested at the NASA Ames Research Center's Dryden Flight Research Facility. This system, the adaptable target lighting array system (ATLAS), is based on the German Aerospace Research Establishment's ground attack test equipment (GRATE). These systems provide a flying-qualities task, emulating the ground-attack task with ground deployed lighted targets. These targets light in an unpredictable sequence and the pilot has to aim the aircraft at whichever target is lighted. Two flight-test programs were used to assess the suitability of ATLAS. The first program used the United States Air Force (USAF) NT-33A variability stability aircraft to establish that ATLAS provided a task suitable for use in flying qualities research. A head-up display (HUD) tracking task was used for comparison. The second program used the X-29A forward-swept wing aircraft to demonstrate that the ATLAS task was suitable for assessing the flying qualities of a specific experimental aircraft. In this program, the ground-attack task was used for comparison. All pilots who used ATLAS found it to be highly satisfactory and thought it to be superior to the other tasks used in flying qualities evaluations. They have recommended that it become a standard for flying qualities evaluations.

Nomenclature

AGL	above ground level
ATLAS	adaptable target lighting array system
DFRF	Dryden Flight Research Facility
DLR	German Aerospace Research Establishment, formerly DFVLR
FDL	Flight Dynamics Laboratory
GRATE	ground attack test equipment
HAVE ATLAS	USAF Test Pilot School-sponsored ATLAS test program
HUD	head-up display
KIAS	knots indicated air speed
LAMARS	large amplitude multimode aerospace research simulator
NASA	National Aeronautics and Space Administration
USAF	United States Air Force
WRDC	Wright Research and Development Center

Introduction

To assess the flying qualities of an aircraft accurately requires a high-gain, precise, repeatable, and well-defined task. This task must be performed consistently by all pilots involved in the test program and must have clearly defined levels of satisfactory and acceptable performance. In addition the task must be safe. It is also desirable for the task to be realistic, resembling one that might be encountered in operational flying.

A new approach to flying-qualities task definition was undertaken at the German Aerospace Research Establishment (DLR) Institute for Flight Mechanics in the early 1980s, when a system known as the ground attack test equipment (GRATE) was developed and tested with success.[1,2,3] The GRATE system emulates the ground-attack task with lighted targets. The targets light in an unpredictable sequence and the pilot has to aim the aircraft at whichever target is lit. This task meets all the criteria—high-gain, repeatable, precise,

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and safe. This task was also implemented in the large amplitude multimode aerospace research simulator (LAMARS) at Wright-Patterson Air Force Base.[3,4]

In 1987 NASA Ames Research Center's Dryden Flight Research Facility (DFRF) developed a functional equivalent of the GRATE system for use at Edwards Air Force Base. This system, known as the adaptable target lighting array system or ATLAS, was initially flight-tested in a developmental form in late 1988. The ATLAS is functionally equivalent to the GRATE system but the implementation is quite different.

Four different fighter-type aircraft were flown using ATLAS in two flight-test programs. The first of these programs, known as HAVE ATLAS, was a senior project at the USAF Test Pilot School.[5] This program established the procedures, including the definition of the task pattern, using a T-38A and the USAF NT-33A variable-stability aircraft. The T-38A was used to establish the test procedure and train the pilots. Two tasks, ATLAS and a head-up display (HUD) tracking task, were evaluated with the NT-33A. In addition, the German pilot who flew evaluations using the GRATE system flew the NT-33A using ATLAS.

A subsequent DFRF program used ATLAS to assess the flying qualities of the X-29A forward-swept wing aircraft. A TF-104G was also used for pilot familiarization. The flying qualities of the X-29A had previously been evaluated using a simulated ground-attack task.

This paper briefly describes ATLAS and presents the results of the two initial flight-test programs.

ATLAS Description

A block diagram of ATLAS is shown in Fig. 1. The system is a stand-alone ground-based system consisting of a receiver–controller, an encoder and transmitter, and nine targets. Each target consists of a receiver, a decoder, and a target lamp. The task is initiated when the pilot turns the system on using the aircraft radio. All of the target lamps light simultaneously for five seconds to allow the pilot to acquire the target array and set up the task. The encoder then transmits the identifier of a specific target from the preprogrammed sequence. When the target decoder receives its identifier it turns the target lamp on. The pilot then points the aircraft at the lighted target, using the gunsight or HUD reticle. After a preset interval, a new target is designated and the pilot again changes aim point. This continues until the preprogrammed sequence ends. At this time the target lamps light simultaneously for two seconds to show the pilot the task is complete.

The receiver–controller, used to start the sequence, is designed to control runway lights at small general-aviation airports. The encoder is a microcomputer containing the preprogrammed target sequences. These sequences are sent to the transmitter. The transmitter then broadcasts the target command, which is received at each target. The microcomputer decoder lights the target lamp if its identifier is received.

The system deployed in this initial testing was a prototype system. It was deployed in a remote location and used portable generators for power. At the time of initial testing, seven targets were available.

The number of targets used in the preprogrammed sequences and the length of time that the targets were lighted are predetermined, based on the type of aircraft and the speed at which it flies. This is a safety-of-flight issue, as it is necessary to ensure that the sequence ends when the test aircraft is still above a safe altitude.

The preprogrammed sequences are generated by two computer programs (provided by DLR) run on a mainframe computer. The first program is used to define the size and shape of the target array, based on airspeed, initial and final altitudes, and dive angle. The second program generates the target sequences. These sequences, based on the number of targets used in the sequence, position of the targets, and length of time each target was to be lighted, were optimized for angular displacements in both the longitudinal and lateral-directional axes. The sequences are programmed into the ATLAS encoder prior to deployment.

The nominal target pattern, shown in Fig. 2(a), is a diamond 350 m long and 120 m wide, using nine targets. Since only seven targets were available at the time of testing, the pattern was initially modified, as shown in Fig. 2(b), for the HAVE ATLAS program. The pattern shown in Fig. 2(c) was used to provide more lateral motion in the task for the X-29A evaluations. The evaluation task started at 5500 ft above ground level (AGL) and ended at 1500 ft AGL. The nominal dive angle was 15° and the airspeeds ranged from 300 to 400 KIAS.

Flight-Test Procedure

Test Aircraft

The T-38A aircraft used has a HUD, but is otherwise unmodified. It has no instrumentation. The T-38A was used to establish procedures, provide pilot proficiency, and evaluate the initial usefulness of the ATLAS task. This aircraft was not used for flying qualities evaluations. The T-38A was flown at 400 KIAS.

The NT-33 aircraft (Fig. 3) is a two-seat, variable-stability aircraft with an analog-digital hybrid control system. This aircraft, a flying-qualities research tool, has instrumentation and a programmable HUD. This HUD has a computer-generated tracking task, which is used for flying-qualities evaluation. Another HUD display is a reticle, used for the ATLAS task. Because it is a variable-stability aircraft, the flight characteristics of this aircraft can be varied, as selected by the safety pilot in the rear seat. The basic flight characteristics used in this program were chosen to provide good, Level 1 handling qualities. This aircraft was flown at 300 KIAS for both the ATLAS and HUD tracking tasks.

The TF-104G aircraft is an unmodified interceptor. The aircraft, used only for pilot training and proficiency, has no HUD and no instrumentation. This aircraft was flown at 400 KIAS.

The X-29A aircraft (Fig. 4) is a single-seat experimental aircraft with a forward-swept wing. The aircraft, which is extensively instrumented, has a highly augmented fly-by-wire flight control system. Prior to the ATLAS program, an extensive flying qualities study was performed with this aircraft, using ground-attack and formation flight tasks. The pilots characterized the simulated ground attack task as ill-defined, not very consistent or repeatable, and subject to anticipation by the pilot. The ATLAS task was flown at 400 KIAS, and used the gunsight as the aiming device.

ATLAS Task

The task, which resembles the ground-attack task, is shown in Fig. 5. The pilot flies around the ground track shown and, when he rolls in on the evaluation leg, clicks the microphone seven times to start the target sequence. At the end of the target sequence he pulled up and climbed back to the pattern altitude (7500 ft AGL) on the crosswind leg. The time on the downwind leg is used to rate the aircraft and complete the pilot comments. Desired and adequate performance for the task is identified in advance for each aircraft. The pilots used the HUD reticle (for the T-38A and NT-33A) or the gunsight (for the X-29A) as the aiming device.

The target pattern shown in Fig. 2(b) was used with the T-38A and NT-33A aircraft and the pattern shown in Fig. 2(c) was used with the TF-104G and X-29A aircraft. The wider target pattern was selected because prior X-29A testing had indicated some deficiencies in the lateral-directional flying qualities of the aircraft.

Target Sequences

Five sets of sequences were used in various portions of the two programs. The number of targets lighted and the length of time that each target was lighted are detailed in Table 1. (An individual target could appear more than once in a target sequence.) The targets light in a sequence that appears to be random and the pilot does not know which sequence is being used. The sequences are optimized for longitudinal or lateral displacements, or both.

The number of targets lighted in a sequence was a function of the airspeed of the test aircraft and the length of individual target illumination. For the 400 KIAS task (the T-38A, TF-104G, and X-29A), the total length of the sequences was about 25 sec, including the 5-sec initial aiming portion and the 2-sec end portion, where all targets were lighted. For the 300 KIAS task (the NT-33A) the total length of the sequences was approximately 30 sec, including the initial and end portions, since the lower airspeed provided more time for the evaluation. For all aircraft the sequences were ordered so that the length of target illumination varied from sequence to sequence.

NT-33A HUD Tracking Task

The NT-33A HUD tracking task, generated in the onboard computer, was used as a comparison to the ATLAS task. This task has been used in previous flying qualities evaluations.[6] It is a good flying qualities task, being well defined and repeatable.

Table 1. Description of target sequences.

Aircraft	Number of Targets Illuminated	Length of Target Illumination (sec)
T-38A	6	3.1
	6	3.4
	5	3.7
	5	4.0
	4	4.3
NT-33A	8	3.1
	8	3.4
	7	3.7
	7	4.0
	6	4.3
NT-33A*	9	2.4
	9	2.6
TF-104G	7	3.1
	6	3.4
	5	3.7
X-29A	7	3.1
	6	3.4
	5	3.7

*Used by German pilot on his third flight.

This task is illustrated in Fig. 6. The tracking task is provided by the moving command bar, which moves in both pitch and roll. As a series of pitch and roll inputs is made by the computer to this command bar, the pilot must maneuver the aircraft to align the fixed aiming symbol with the command bar. The display also has a horizon line. Desired and adequate performance for this task was defined in advance.

Time Delays

To provide a known degradation of the flying qualities of the NT-33A, time delays were added to the aircraft control system in both the longitudinal and lateral axes. These delays were added in the command path, after the feel system dynamics. The time delays used in the ATLAS evaluations were selected to have no effect, little effect, moderate effect, and severe effect (0, 90, 130, and 180 msec respectively).

For comparison purposes the 0 and 180 msec time delays were used when evaluating the HUD tracking task.

Data Acquisition

Data acquired included pilot opinion ratings of the flying qualities using the Cooper-Harper rating scale, pilot comments about the flying qualities, and pilot assessment of the ATLAS task itself. In both programs the pilot was asked to compare the ATLAS task with other flying-qualities tasks, including the ground-attack task. In the NT-33A the pilot was also asked to compare the ATLAS and HUD tasks.

Aircraft dynamic response data were available in the instrumented aircraft and were collected for future analysis. Where available, HUD video tape or gun camera footage was also collected. This footage was used by the flying qualities researcher and the pilot in post-flight discussion and review of the task, the aircraft flying qualities, and the pilot ratings and comments.

Results

The first part of the HAVE ATLAS program was initial flight testing, using the T-38A aircraft to establish the flight pattern and procedures. To do this, four sorties, two by each pilot, were flown. The pilots found the ATLAS task to be well-defined and easily standardized.

The second phase of the program was the NT-33A testing. An aircraft configuration with good flying qualities was selected and time delays of 0, 90, 130, and 180 msec were added to the flight-control system. When these four configurations were flown using ATLAS, the changes in the flying qualities were perceptible. Figure 7 shows the pilot rating and time delay, plotted against run number, for one typical sortie. As can be seen, the increase in pilot rating correlates with the increase in time delay as predicted. Six evaluation flights, three for each pilot, were flown in this phase. Figure 8 summarizes the results. The average pilot ratings are plotted against time delay for the ATLAS and HUD tracking tasks in Figs. 8(a) and (b), respectively, for pilot A and in Figs. 8(c) and (d), respectively, for pilot B. The vertical line indicates the range of pilot ratings. The wide range of ratings is not uncommon for degraded aircraft, particularly for less experienced pilots. It can be seen that this range is reduced in later flights, showing the effect of learning. Figure 8(e) shows the average ratings for both pilots for the ATLAS and HUD tasks. The average ratings for the two tasks agreed well, validating the discrimination of the ATLAS task.

The pilots found the ATLAS task to be well defined, with desired and acceptable performance easily determined. The HUD task was considered less desirable by the pilots, who characterized the task as being more like a video game than a realistic task. The pilots thought that their gain was higher for the ATLAS task because the task was more demanding and more realistic. The pilots were unable to distinguish any differences in the length of time the targets were lighted in the target sequences. The major recommendation made by the pilots was that ATLAS be used in flying qualities investigations as well as being used to evaluate the flying qualities of specific aircraft.

The German test pilot who used GRATE also flew the NT-33A using ATLAS. He said that GRATE and ATLAS were functionally equivalent and he was also able to distinguish the various additional time delays. After his first flight in the NT-33A, this pilot thought the sequences used lighted the targets too long, based on his experience with the GRATE system. His last flight used sequences with shorter times, which he found to be satisfactory.

Because the HAVE ATLAS program produced such positive results and because the pilots had identified deficiencies in the simulated ground-attack task, the next use of ATLAS was to incorporate it into a DFRF flight-test program using the X-29A aircraft. To familiarize the two X-29A pilots with the ATLAS location and procedures, a TF-104G was flown on one flight. The X-29A then flew using ATLAS during three flights, with two pilots. The aircraft was rated as Level 1 in pitch and Level 2 in roll, which corresponds with ratings from other tasks. In post-flight debriefings and flight reports, these pilots characterized the task as extremely effective; being safe, repeatable, and precise. They also thought that the resemblance to the ground-attack task decreased the time needed to become familiar with the task and that the apparent randomness of the sequences raised pilot gain and eliminated precognitive behavior. Both pilots recommended that this system become a standard for flying qualities evaluations, since it can be used as a general task, and is not limited to ground-attack evaluations. These pilots were also unable to distinguish any difference in the length of time the targets were lighted.

Conclusions

Based on the results of these tests, ATLAS (like GRATE) provides a safe, high-gain, precise, and repeatable task. The pilot cannot anticipate the sequence and precognitive behavior does not occur. The test pilots who used ATLAS preferred it to a variety of other tasks for flying qualities assessment, saying that the task was safe, well defined, and consistent.

The results of the X-29A program demonstrated that although ATLAS is a prototype system, it is suitable for operational use.

Although this task resembles the ground-attack task, it is a more general task and is suitable for use with all aircraft, not just attack aircraft. However, the resemblance to the ground-attack task provides realism and reduces the training required by the pilot to a certain extent.

ATLAS is suitable both for assessing the flying qualities of a specific type of aircraft (i.e., specification compliance) and for general flying qualities research (i.e., using variable-stability aircraft).

Acknowledgements

These programs would not have been possible without the efforts and expertise of Mr. Glenn Bever, of the DFRF Fluid and Flight Mechanics Branch. He is responsible for the final working version of ATLAS.

Herr Karl-Heinz Lang, of the Federal Armed Forces Engineering Center for Aircraft, provided assistance as the pilot who flew using the GRATE system.

The USAF/Calspan NT-33A is operated by the Arvin/Calspan Advanced Technology Center, Buffalo, New York, for the Flight Dynamics Laboratory (FDL) Wright Research and Development Center (WRDC) Wright-Patterson Air Force Base, Ohio. Mr. Steven R. Markman of the Flight Dynamics Laboratory was the USAF program manager. The USAF Test Pilot School sponsored the "HAVE ATLAS" program and WRDC, represented by Mr. Robert Woodcock, sponsored Herr Lang's flights. Mr. Louis H. Knotts, of Calspan, was the safety pilot for all NT-33A flights.

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[6] Bailey, R.E., and Knotts, L.H., *Interaction of Feel System and Flight Control System Dynamics on Lateral Flying Qualities*, Technical Report 7205-26, Arvin/Calspan Advanced Technology Center, Dec. 1988.

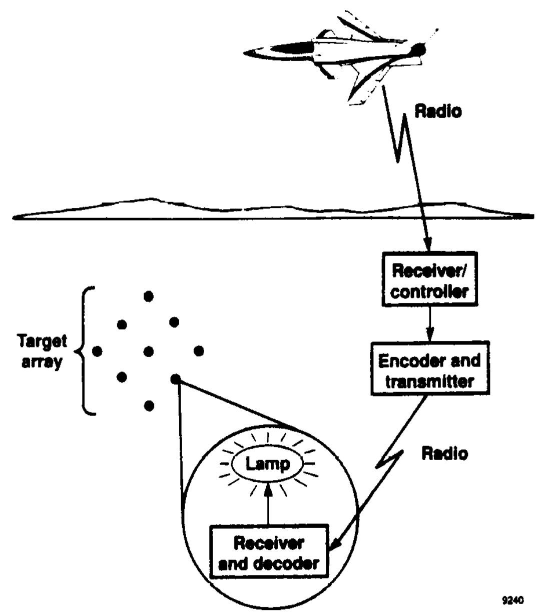
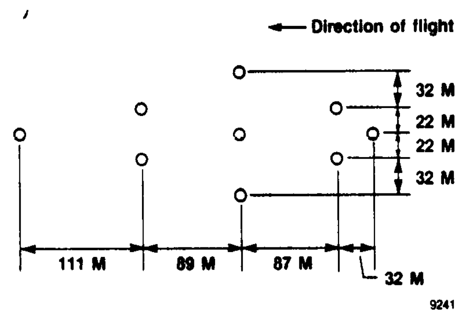
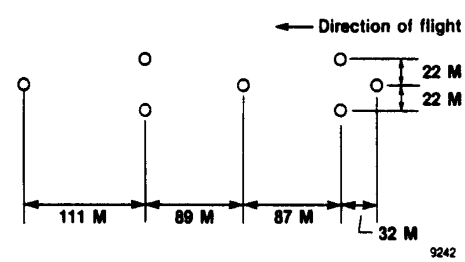


Fig. 1 ATLAS block diagram.

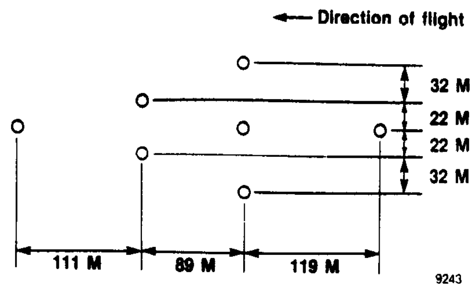


(a) Nominal pattern.



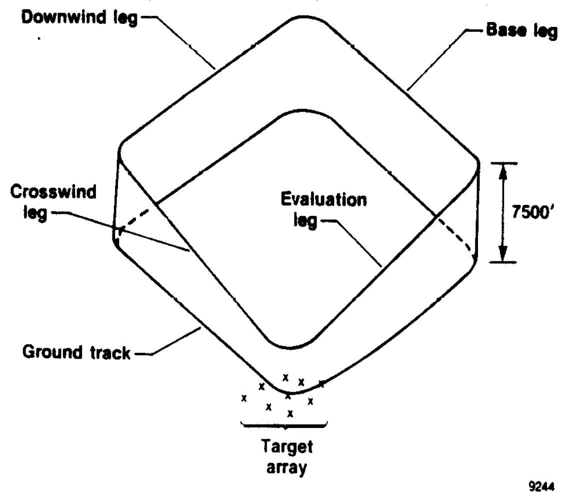
(b) Target pattern used for T-38A and NT-33A.

Fig. 2 ATLAS target array pattern.

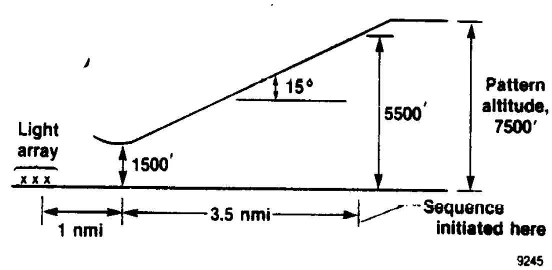


(c) Target pattern used for TF-104G and X-29A.

Fig. 2 Concluded.



(a) ATLAS ground track.



(b) ATLAS task profile.

Fig. 5 ATLAS ground track and task profile.

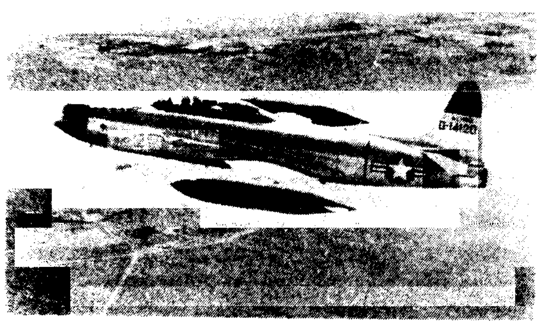


Fig. 3 NT-33A aircraft.

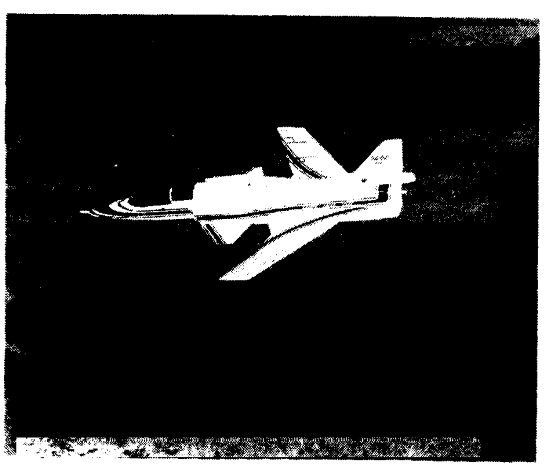


Fig. 4 X-29A aircraft.

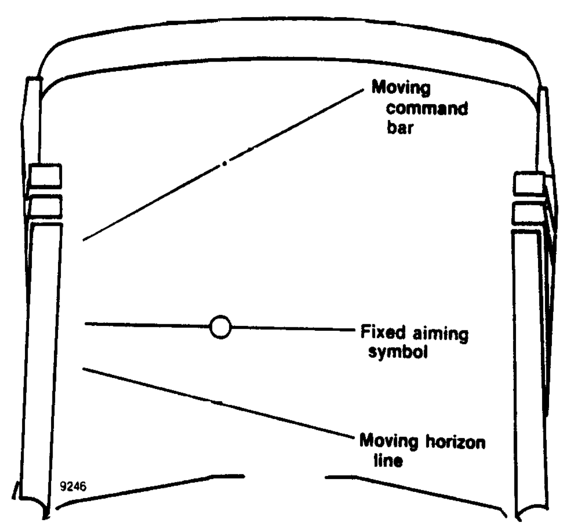


Fig. 6 NT-33A HUD tracking task.

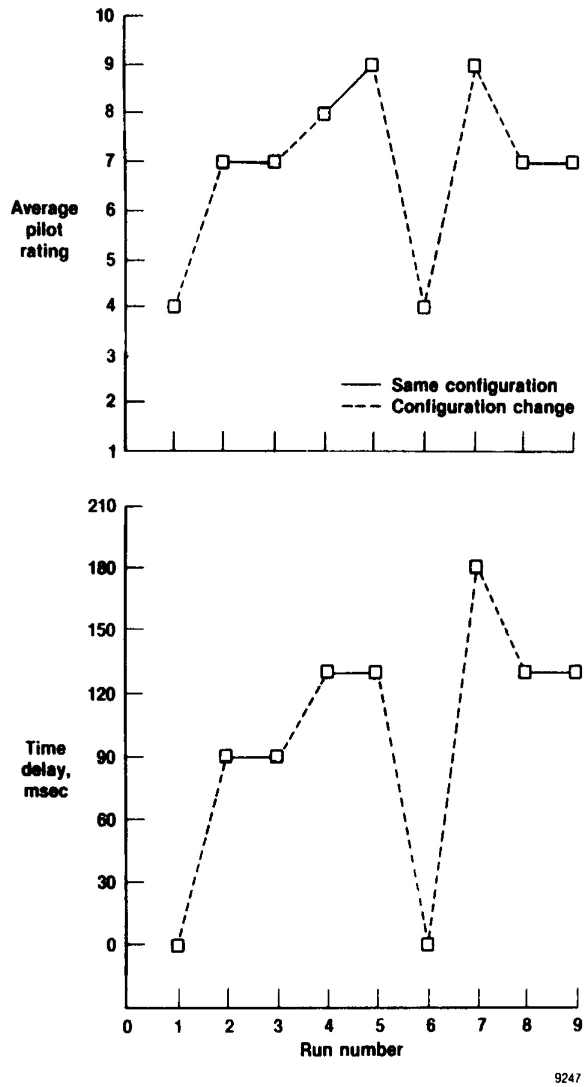
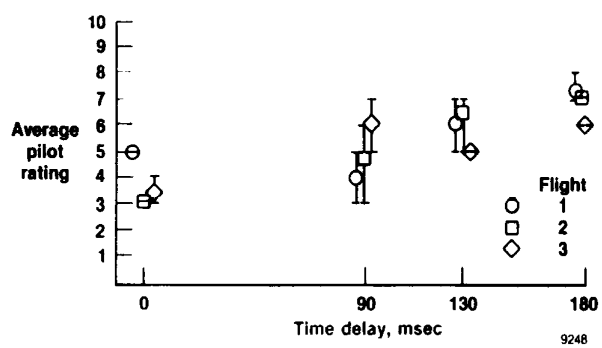
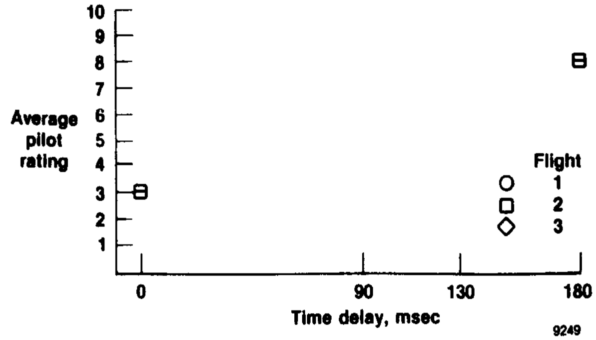


Fig. 7 Pilot ratings and time delays for a typical NT-33A flight.

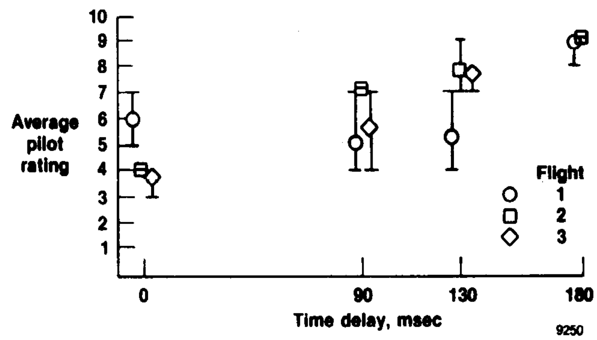


(a) Summary of ratings for ATLAS task, pilot A.

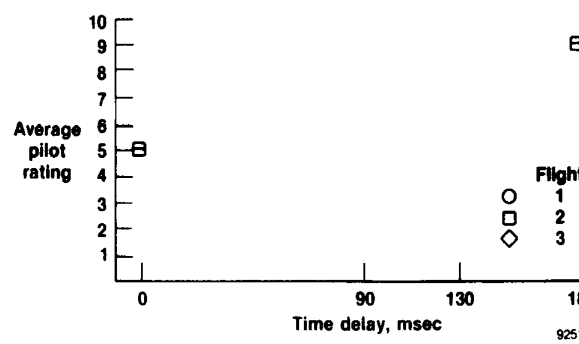
Fig. 8 Summary of ratings for NT-33A ATLAS and HUD task evaluations. Horizontal lines represent range of ratings.



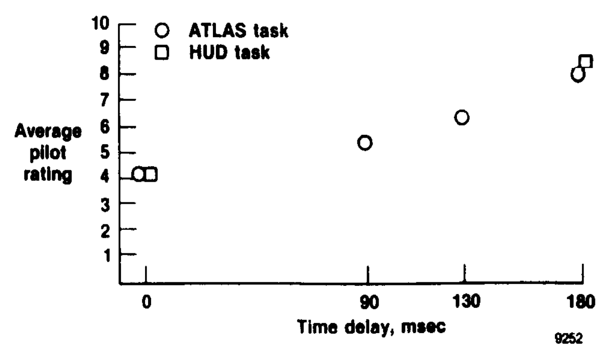
(b) Summary of ratings for HUD task, pilot A.



(c) Summary of ratings for ATLAS task, pilot B.



(d) Summary of ratings for HUD task, pilot B.



(e) Summary of ratings for ATLAS and HUD tasks.

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16. Abstract

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